Executive Summary

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30th Annual American Helicopter Society
Student Design Competition
Graduate Student Team Submission

University of Maryland, College Park

The *HeliX* is the University of Maryland's (UMD) submission in response to the Request for Proposal (RFP) for the 2013 AHS Student Design Competition, co-sponsored by Eurocopter. The *HeliX* is a variable diameter tiltrotor concept designed to have unprecedented capabilities in the realms of range, speed, and endurance. In addition to boasting advanced performance characteristics, careful consideration was put into the design of the command structure, decreasing pilot workload while ensuring the safety of all occupants. It is these key components that make the *HeliX* a superior Search and Rescue platform, ideal for rescues in a vast array of operating conditions.

The success of the *HeliX* can be attributed to the implementation of optimized systems as well as to the use of innovative design features including:

- ✓ The variable diameter proprotor for increased efficiencies in both hover and forward flight

- ✓ The outboard wing extensions (OWEs) that increase the wing aspect ratio and aid in the achievement of airspeeds in excess of the 240 kts required by the RFP and also provide additional lift

RFP Requirements

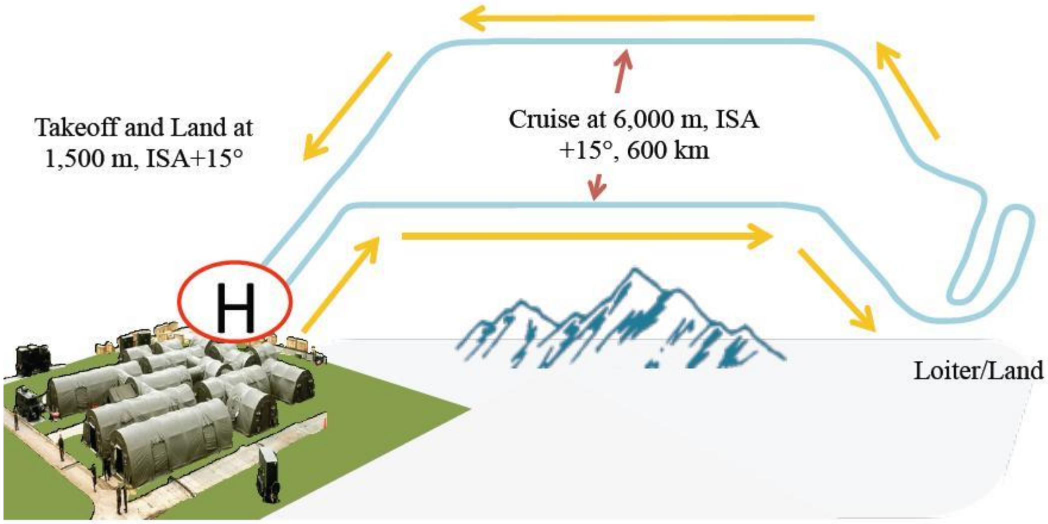
The 2013 AHS RFP has specified a number of design points that that must be accounted for. Some of the driving factors include:

- ***Long range deployment***: The RFP assumes that the base out of which operations will occur is a minimum of 600 km from the disaster site. This requires that the designed vehicle be capable of ranges in excess of 1,200 km without the need to refuel.

- ***High-altitude cruise***: All cruise segments of the three missions are required to take place at 6,000 m, ISA+15°C. Historically, no pure rotary aircraft have been capable of these altitudes at the RFP specified airspeeds.

- ***Minimal crew***: Due to the uncertain nature of disasters, the ability to run a rescue mission with minimal staffing is important. The RFP mandates that the proposed vehicle is capable of being flown with a three person crew so high autonomy is crucial.

- ***Useful load requirement***: A minimum 6 metric ton useful load (payload+fuel) is required for each mission.



Segment	Requirement
1	Start and warm up at 1,500 m ISA+15°
2	Climb to 6,000 m, ISA +15°
3	Accelerate and cruise 600 km
4	Descend
5	Loiter/Land (mission specific)
6	Takeoff and/or climb
7	Accelerate and cruise 600 km
8	Descend and land

Specified Missions

- **Aerial Triage**
  - ✓ *Fast deployment*: After the occurrence of a disaster it is imperative that rescue operations commence as quickly as possible. This vehicle configuration must get to the disaster zone as quickly as possible in order to gather data which will be used to coordinate rescue operations.
  - ✓ *Reconnaissance*: During this mission the vehicle is required to perform a long endurance, relatively low-speed loiter. This segment is crucial for examining the disaster area and determining the nature of relief required.

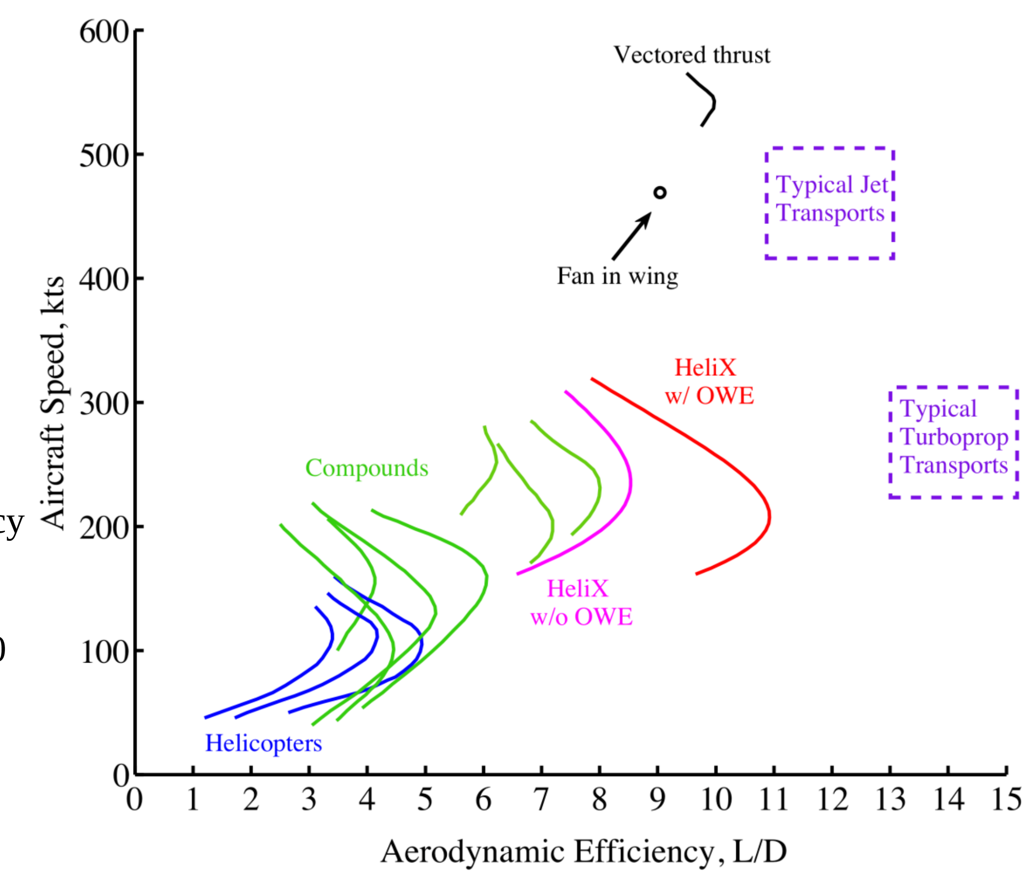
- **Aid Distribution**
  - ✓ *Distribution of relief materials*: During this mission, the vehicle must carry at least 2 metric tons of relief material to the disaster site 600 km away. Once on scene, distribution of this material must occur within an hour's time.

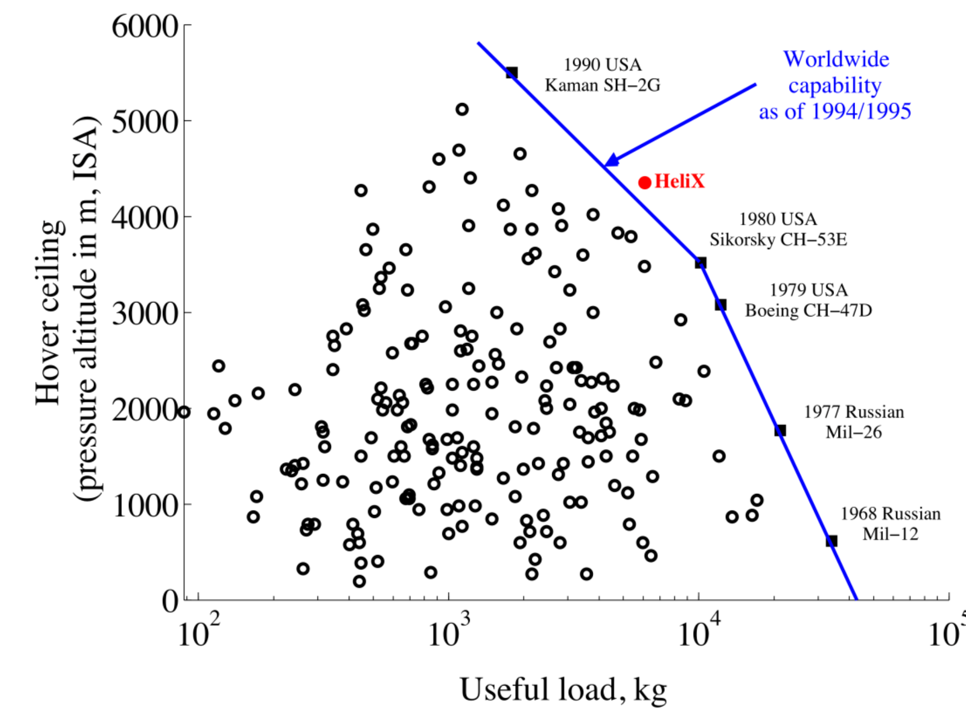
- **Casualty Evacuation (CASEVAC)**
  - ✓ *Victim Rescue*: In the wake of almost any disaster, there will be victims who require medical attention. The vehicle must be capable of retrieving a minimum of 6 wounded. This third vehicle configuration must get to and from the disaster zone quickly in order to increase the chances of patient survival. It is well established that a patient's chance of survival are greatest if care if received within a short time of injury, ideally within the "golden hour." Once on scene, the RFP requires that the 6 patients must be loaded within a 30 minute timeframe.

The UMD Team designed a tiltrotor based on the requirements given by the RFP. Not only is this a design platform that is proven in the field, but one that has not been explored to its full potential. Compound designs, such as the Sikorsky X-2 and the Eurocopter X^3, although fast, tend to have high empty weight fractions, a lack of proven scalability, and rotors close to the ground that pose a threat to victims at the disaster site. The tiltrotor provides a platform that has demonstrated its speed, range, and altitude capabilities which made it the best initial configuration candidate.

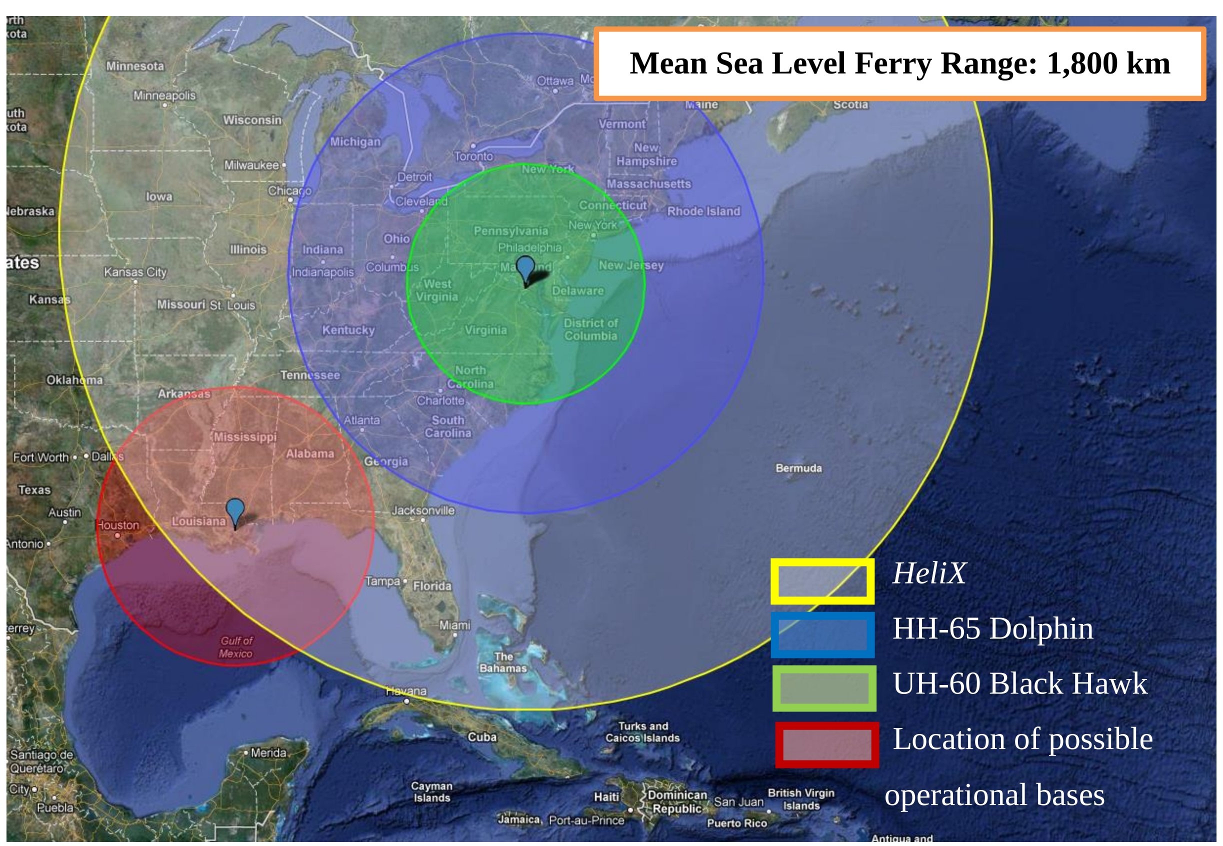
Performance

- MGTOW of 15,260 kg
- **Optimized for speed and range**
  - ✓ MGTOW V_{MCP} = 283 kts
  - ✓ MGTOW maximum range: 3,373 km
- Innovative tiltrotor design
  - ✓ **Outboard Wing Extensions (OWEs)** provide unprecedented L/D ratios in forward flight
  - ✓ **Variable diameter** maximizes performance and efficiency in helicopter and airplane modes
- **High average rate of climb** (from 1,500 m, ISA+15°C to 6,000 m, ISA+15°C) of 2,408 ft min^{-1}
- **Exceptional hot-and-high performance**
  - ✓ MGTOW HOGE altitude of 2,526 m, ISA+20°C
  - ✓ At Mission 3 weight, the *HeliX* is capable of hovering at an altitude of 6,466 m



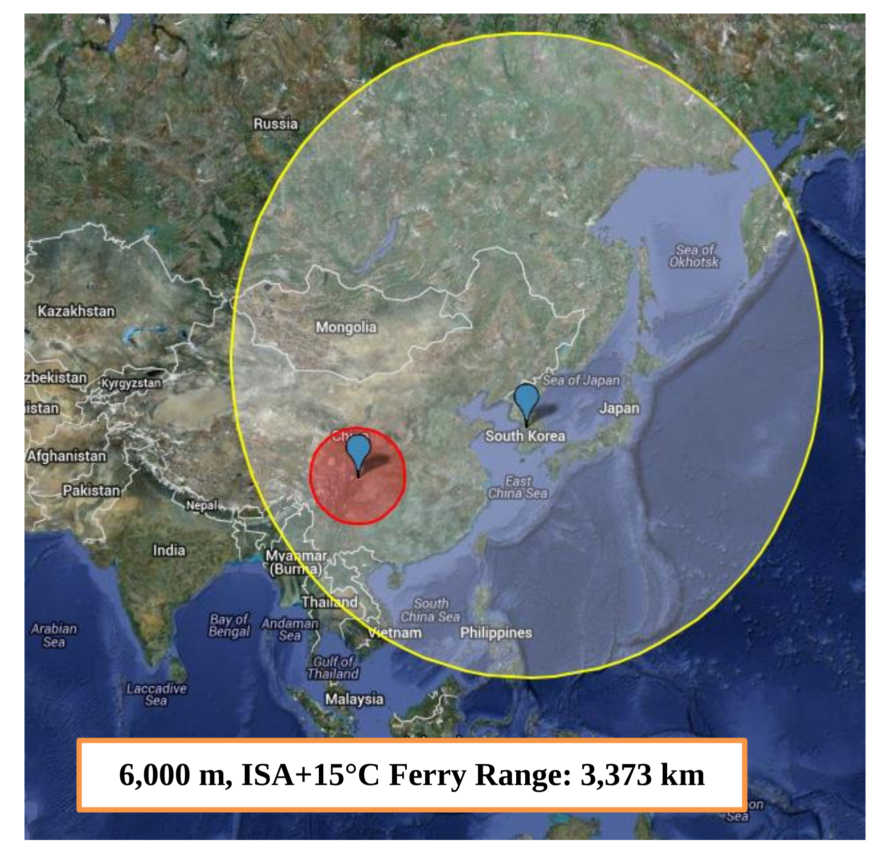


It should be noted that the *HeliX*'s performance characteristics exceed the mission specifications due to the requirement to satisfy a 6 metric ton useful load in each mission set by the RFP. Had the *HeliX* only been sized to perform with the mission specific payloads, the vehicle would have been significantly smaller.



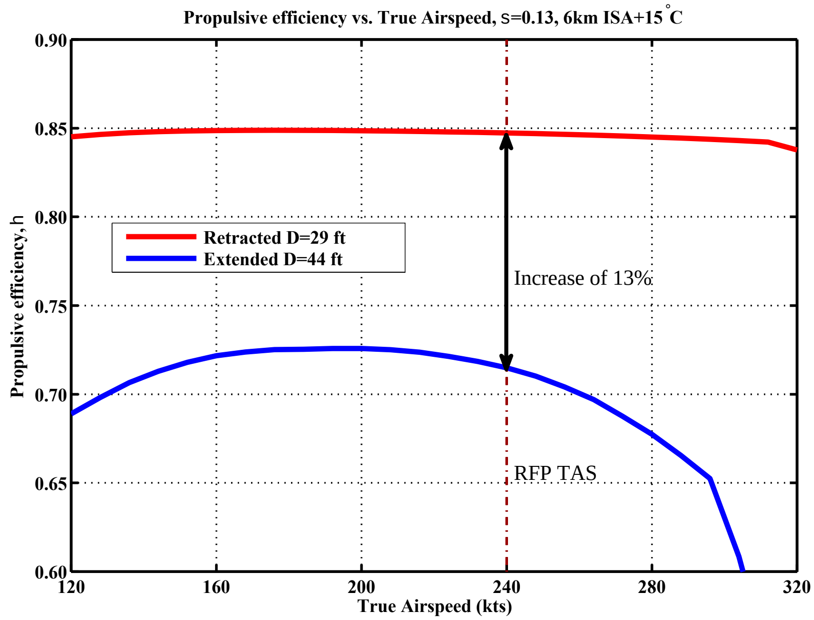
LEFT: The red circle seen in the figure to the left has a radius of 600 km centered on New Orleans, LA and the circumference indicates all the possible locations the operational base could be located. If **deployed from the US Coast Guard Surface Forces Logistics center**, in Baltimore, MD, the *HeliX* clearly outperforms both the Dolphin and the Black Hawk, and is the only vehicle capable of reaching base camp without refueling.

RIGHT: At the RFP cruise design point of 6,000 m, ISA+15°C, the *HeliX*'s self-deployable range increases to 3,373 km. As seen in the figure to the right, if deployed from the **Air Force Base in Pyeongtaek, South Korea**, the *HeliX* would be capable of reaching any operational base around the Sichuan Province of China, which was devastated by an earthquake in 2008.



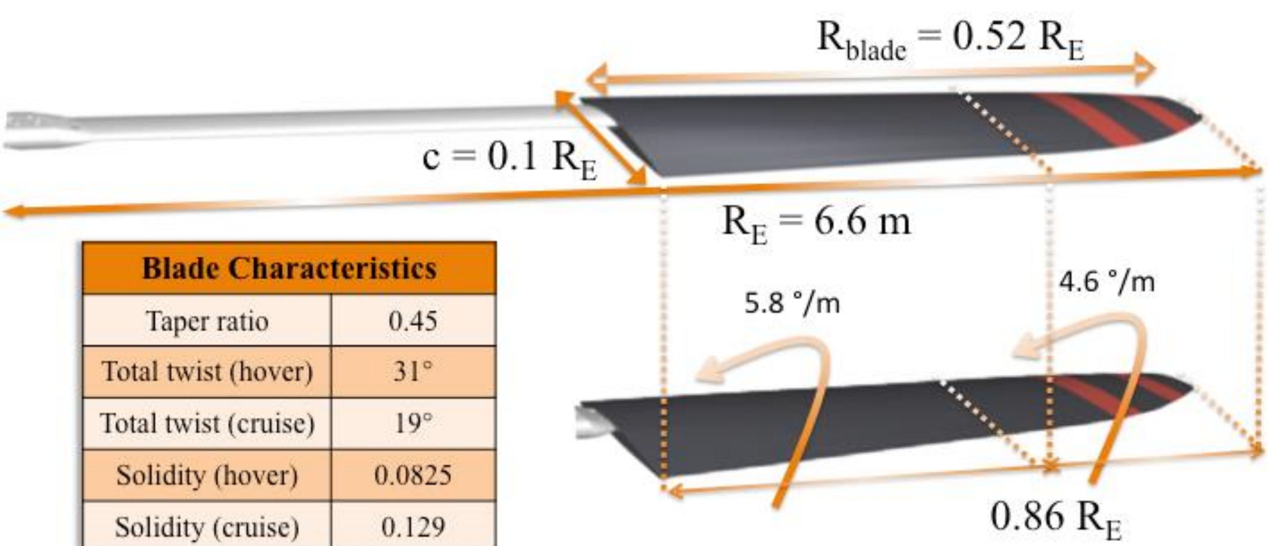
Proprotor Design

The *HeliX* offers **excellent propulsive efficiency** for a wide range of operating conditions while maintaining sufficient hover efficiency, despite the dissimilar design drivers between these flight conditions. This success was only achieved through the design of a **variable diameter rotor**.



Compared to using extended blades in forward flight, retraction produces :

- ✓ 13% increase in η_P for V_{MCP} = 240 kts
- ✓ 17% increase for V_{MCP} = 283 kts.



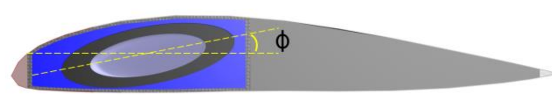
Blade Characteristics	
Taper ratio	0.45
Total twist (hover)	31°
Total twist (cruise)	19°
Solidity (hover)	0.0825
Solidity (cruise)	0.129
η_P	0.85
Figure of Merit	0.71

Variable Diameter Rotor (VDR) System

The 3-bladed rotor of the *Helix* utilizes a unique, telescoping blade system for varying the rotor diameter between hover and forward flight modes of operation. The two primary structural members of the blade consist of an inner, non-lifting element (torque tube) and an outer blade segment. The proporotor blade was designed to meet the demanding needs of the VDR operating environment while maintaining a high level of operational safety, reliability and structural efficiency.

Blade Structural Design

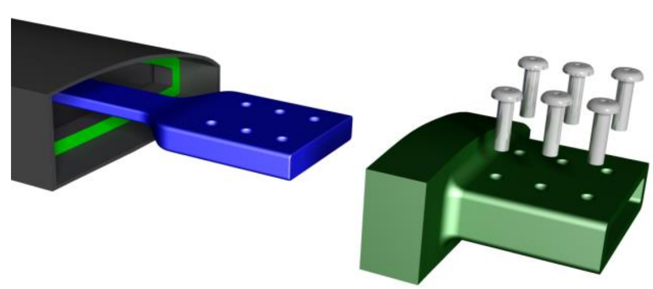
- ✓ A **single-stage telescoping blade system** significantly reduces the overall system weight and complexity compared to other forms of extension/retraction
- ✓ The **ease of manufacturing** of the blade is possible due to the simple elliptical geometry of the torque tube member and conventional design of the outer blade segment
- ✓ A **torque tube angular pitch offset** relative to the outer blade provides a simple, passive method of increasing rotor collective, helping reduce loads placed on pitch links/swashplate actuators



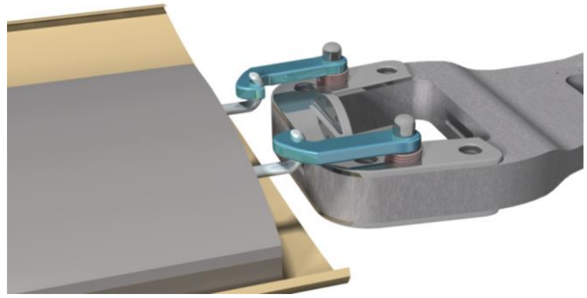
- ✓ **Enhanced leading edge erosion protection and de-icing** is achieved through a polyurethane nano-composite tape and a non-thermal based de-icing technology, both of which provide low rotor maintenance and power consumption
- ✓ **Material Selection** of the latest composite materials provide exceptional blade structural characteristics while maintaining a lightweight design

Extension/Retraction Mechanism

- ✓ **High-strength Kevlar straps** provide load paths for the centrifugal forces of the outer blade during extension/retraction
- ✓ A key advantage of the *Helix's* VDR system is it allows the Kevlar straps to be completely off-loaded when the rotor is in the fully extended or fully retracted mode.



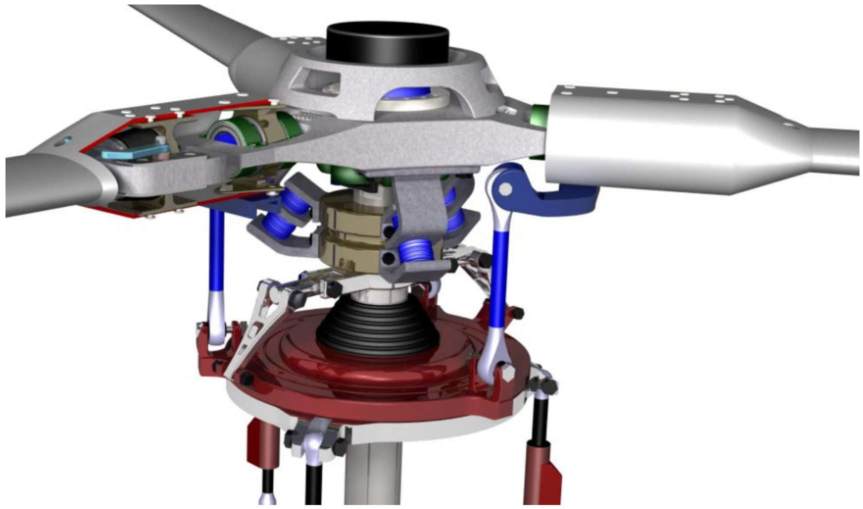
- ✓ Two **fiber-glass/epoxy retention blocks** lock the torque tube and outer blade segment in hover
- ✓ A **blade lock system** is used to fix the position of the outer blade in forward flight to offload the Kevlar strap and extend its usable life



VDR Actuation System

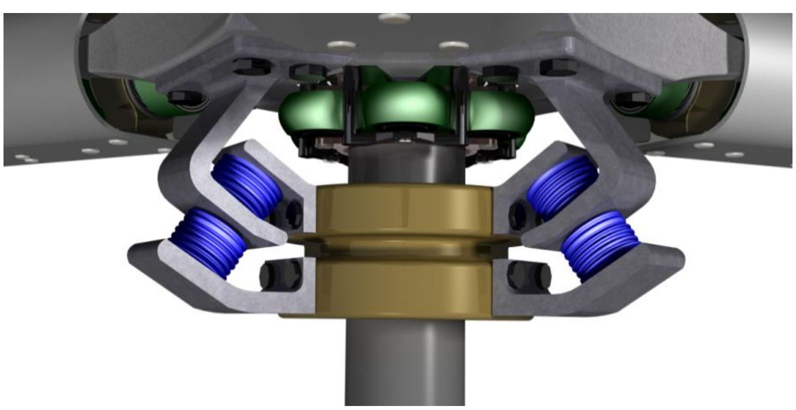
- ✓ A **high-speed, low-torque electric motor** with a feedback control system is used to actuate the extension/retraction of a spooling assembly which houses the Kevlar straps
- ✓ A single-spool assembly ensures **uniform extension/retraction** of the rotor blades, avoiding potential blade imbalances that may otherwise lead to catastrophic failures
- ✓ A unique gear reduction system known as the **harmonic drive system (HDS)** provides a large gear reduction of 1:300 between the motor and spool, while allowing for a compact and light-weight design

Hub Design



The *HeliX* employs a stiff in-plane, gimbaled hub which was specifically designed to accommodate the VDR assembly. The hub is comprised of a composite tailored yoke, constant velocity joint and gimbal assembly, pitch bearing assembly, spool drum, and motor housing. The gimbaled hub provides relief for the 1/rev blade flapping air loads and virtually eliminates Coriolis forces induced by blade flapping. This in turn reduces in-plane bending moments from lead-lag.

- ✓ The **composite yoke structure** allows for reduced weight and is hollow at the center to accommodate the VDR spooling assembly
- ✓ The **all-elastomeric hub design** leads to a reduced amount of moving parts and significantly decreased maintenance costs
- ✓ A unique arrangement of the inner pitch bearing assembly provides the **large pitch range** necessary for forward flight
- ✓ An **elastomeric homo-kinetic drive system** ensures smooth, efficient transfer of torque between the rotor mast and the yoke without inducing vibrations
- ✓ Outer elastomeric hub springs are incorporated to provide **thrust load transfer** between the mast and yoke
- ✓ A key challenge of the hub design was to accommodate the extension/retraction straps and ensure that they are not exposed to ultraviolet light at any point in the operation of the aircraft, which may otherwise damage the Kevlar fibers

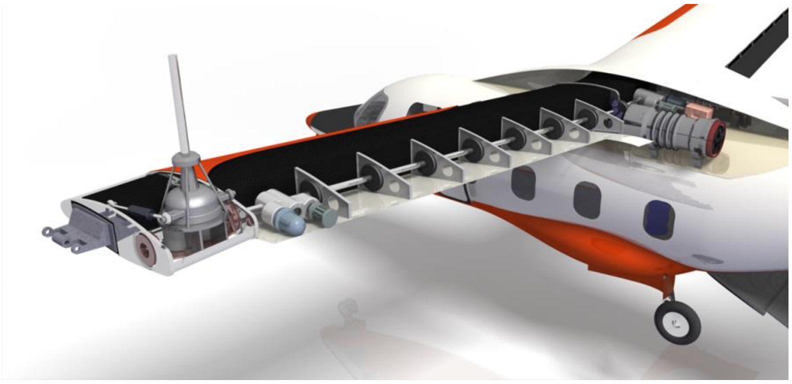


Transmission Configuration

One of the features that immediately distinguishes the *HeliX* from past tiltrotor designs is the center mounted engines. Traditionally, engines are mounted at the wing tips but this leads to an increase in the weight of the wing root structure, increases vehicle inertia, and requires much larger cross-shafting to account for one engine inoperable scenarios.

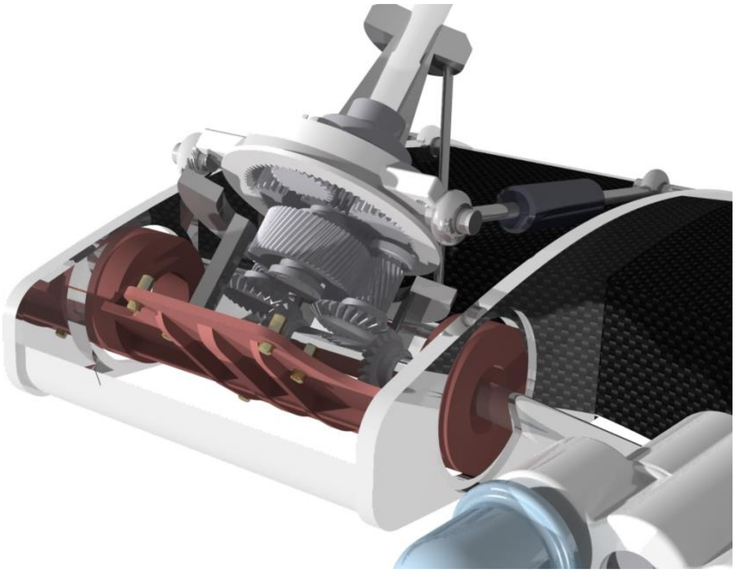
Center Mounted Engines

- ✓ Cleaner, **more aerodynamic wing design**
- ✓ Ensures that patients or **crew are safe from the hot exhaust** during CASEVAC missions
- ✓ Aircraft more ballistically tolerant



The *HeliX* was designed with ***turboshaft engines***, based on the 2007 AHS Student Design Competition “rubber” engine model, for increased reliability and minimized cost.

Dual hydraulic actuators (doubled to reduce actuator size) are used to tilt the nacelle when transitioning from helicopter mode to forward flight mode. The nacelle gearbox steps the engine output RPM to the required rotor RPM in three stages. The use of **both a planetary and split torque stage** allowed for the design of an efficient, relatively light weight gear box. Additionally, the planetary ring was incorporated into the gearbox casing to reduce its weight and size.



Wing Design

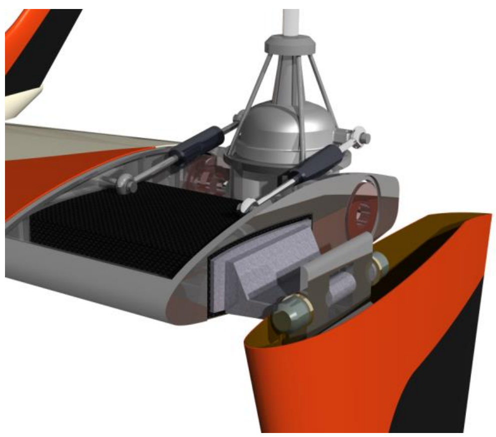
The wing of the *HeliX* is designed to generate all of the necessary lift of the vehicle in forward flight as well as withstand all of the aerodynamic and structural loads the aircraft is expected to encounter during operation. The NACA 65_3-618 airfoil utilized in the wing design provides a shallow drag bucket for a significant range of C_L values, allowing the *HeliX* to operate over a wide range of operating conditions with a low drag penalty.

Structurally, the *HeliX*'s wing is designed not only to satisfy FAR flight load regulations, but also has the required stiffness to prevent the onset of prop-whirl flutter instabilities during high speed flight operations.

- ✓ **Lightweight**, composite design satisfies high stiffness necessary to avoid prop-whirl flutter
- ✓ **Single torque box** design allows storage of all aircraft fuel and housing of interconnecting transmission shafts

- ✓ Out-of-autoclave composite construction process reduces manufacturing costs and permits high quality assurance

One of the unique selling points of the *HeliX* is its implementation of aerodynamically deployed **outboard wing extensions (OWEs).**

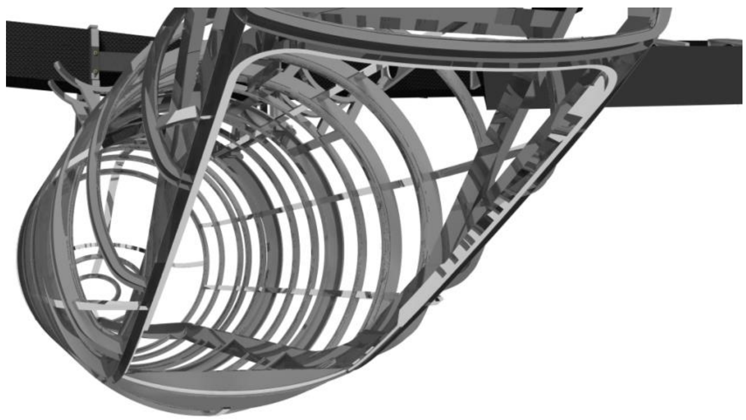


- ✓ **Aerodynamic deployment** of OWEs eliminates the need for the complicated mechanisms required in mechanically-actuated designs
- ✓ Aileron closed-loop control system ensures symmetric OWE deployment and **eliminates additional pilot workload**
- ✓ Deployment aids in reaching a max speed of 283 kts at MGTOW and 317 kts during CASEVAC missions
- ✓ Enables aircraft to achieve a maximum L/D ratio of 10.8, putting the *HeliX* in a VTOL aircraft class all its own

Airframe Design

- ✓ The *HeliX* has a **pressurized cabin** to allow for comfortable flight above altitudes of 8,000 m. There is no current VTOL designed to fly at the altitudes that the *HeliX* is capable of.

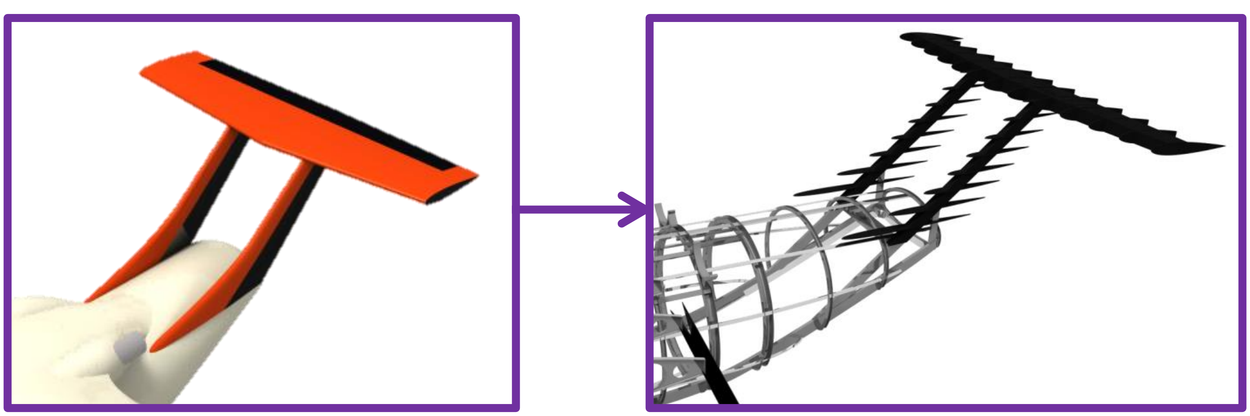
- ✓ The pressurized cabin limits the number of doors available on the *HeliX*. However, a single side-sliding door and **a large aft-loading ramp** accommodate the need for expedited patient loading and cargo delivery.

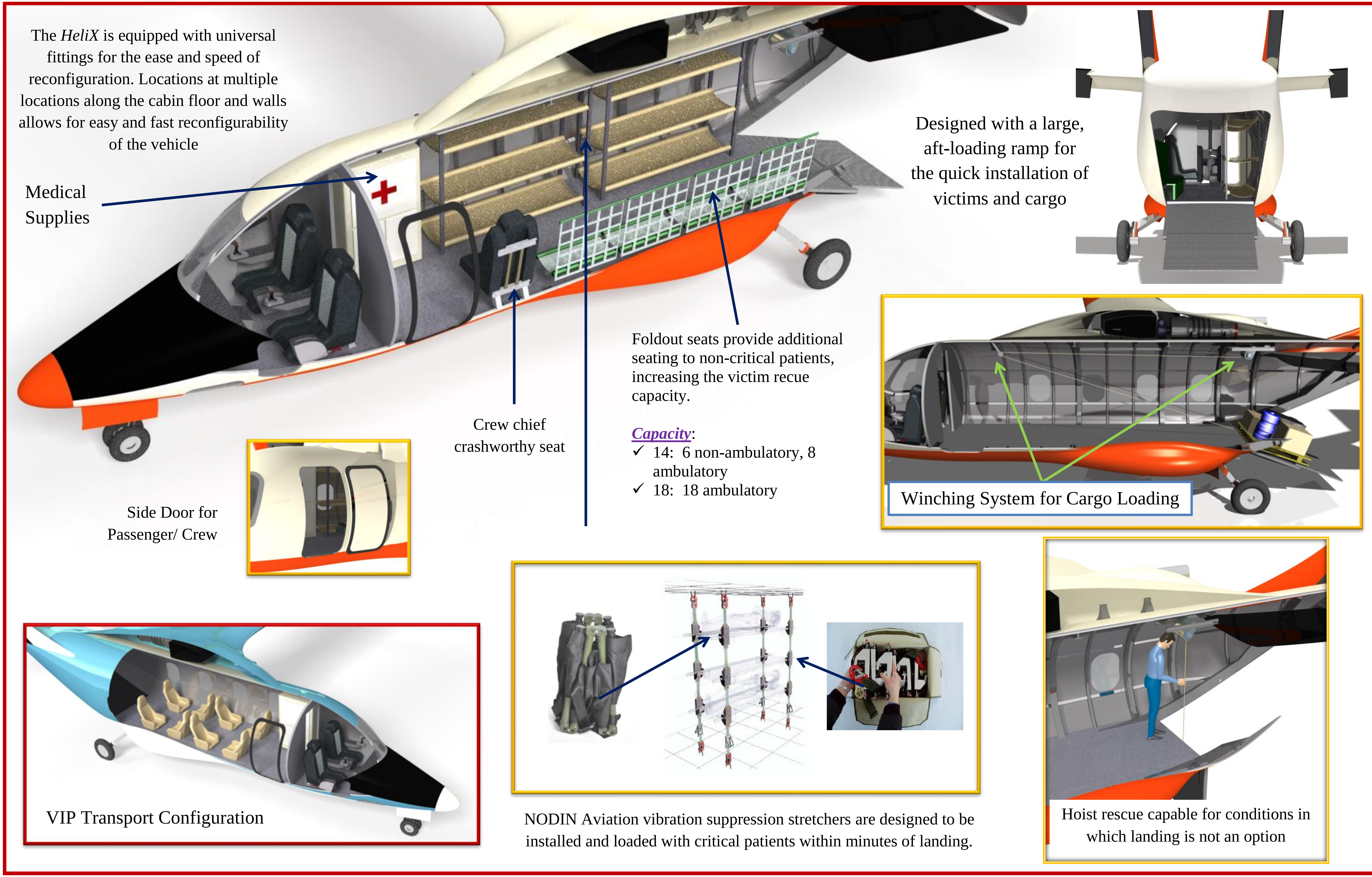


- ✓ The *HeliX* benefits from **a high wing design** to keep rotor blades away from ground operations, ensuring victim and personnel safety around the aircraft.

- ✓ **Retractable landing gear** allows the vehicle to maintain a low drag profile at high forward flight speeds

- ✓ The **innovative Π-tail** allows for improved structural efficiency and reduces the structural weight of the ramp.

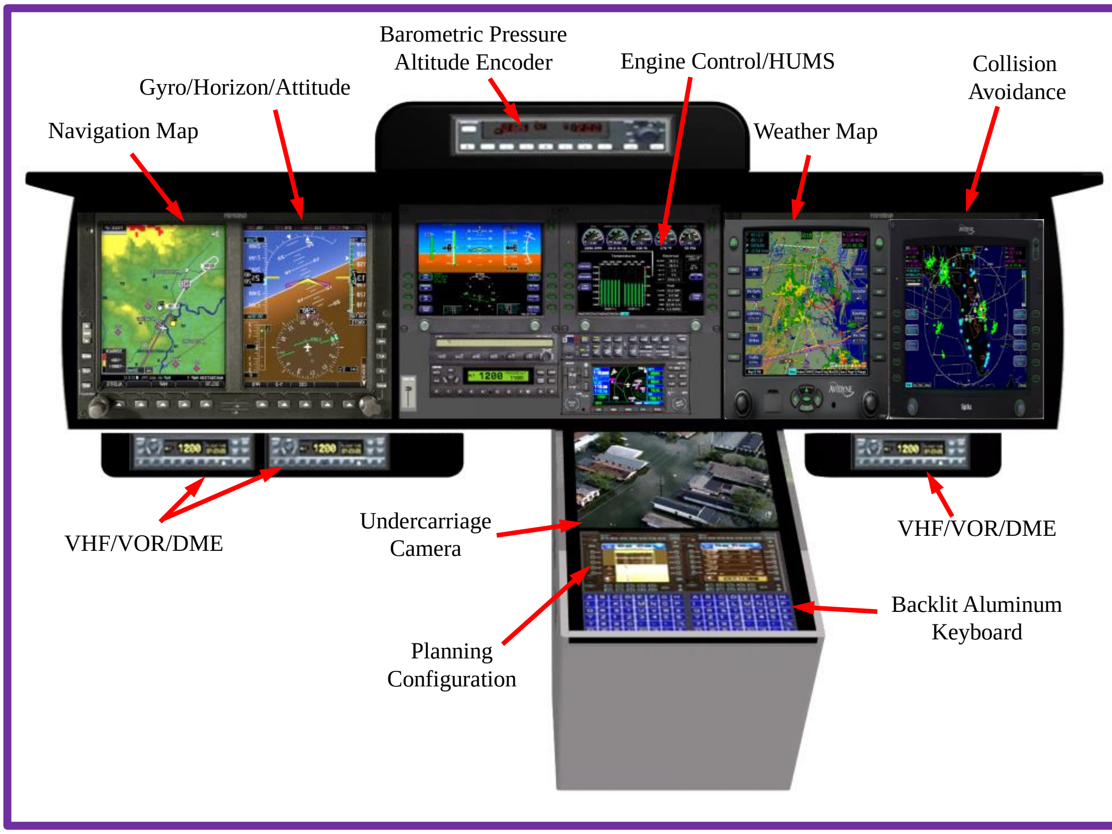



The *HeliX* is equipped with universal fittings for the ease and speed of reconfiguration. Locations at multiple locations along the cabin floor and walls allows for easy and fast reconfigurability of the vehicle
Medical Supplies
Crew chief crashworthy seat
Foldout seats provide additional seating to non-critical patients, increasing the victim recue capacity.
Capacity:
✓ 14: 6 non-ambulatory, 8 ambulatory
✓ 18: 18 ambulatory
Designed with a large, aft-loading ramp for the quick installation of victims and cargo
Winching System for Cargo Loading
Side Door for Passenger/ Crew
VIP Transport Configuration
NODIN Aviation vibration suppression stretchers are designed to be installed and loaded with critical patients within minutes of landing.
Hoist rescue capable for conditions in which landing is not an option

Avionics

Autopilot – As a SAR vehicle, the *HeliX* is equipped to handle degraded visual environments (DVE) that may accompany a disaster situation. Autoflight systems assist the pilot in these conditions, increasing safety and reducing pilot workload.

Datalink – A fleet of the *HeliX* aircraft may be required to operate within a limited airspace. By utilizing the Datalink, the inherent risk of close quarter fleet operations is mitigated. The Datalink offers a highly accurate means of location tracking within the fleet, allowing more vehicles to more safely share a confined airspace, while also reducing pilot workload.



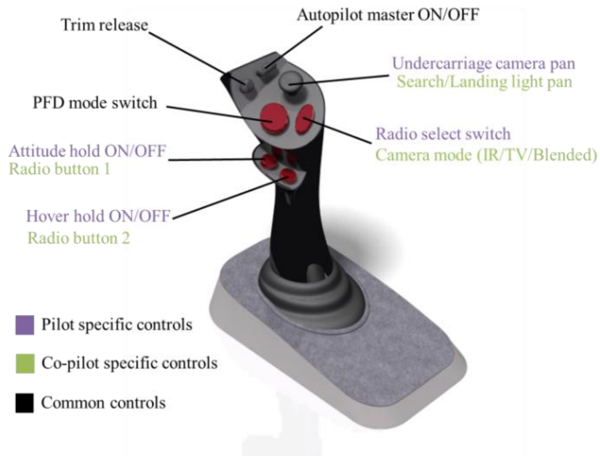
Ice / Rain protection – In order to fulfill the high flight altitude requirements set by the RFP, the *HeliX* requires systems to protect against the accumulation of ice on leading edges of blades and within engine inlets.

HUMS – The *HeliX* employs a **Health and Usage Monitoring System (HUMS)** to continuously check the status of flight critical systems onboard, decreasing the need to follow conservative, fixed interval maintenance practices. HUMS allows for the implementation of condition based maintenance, decreasing total operating costs and minimizing the time between component overhauls.

EGPWS – Disaster zone operations may require flight near ground level in environments with decreased visibility. The *HeliX* is equipped with a Terrain Awareness and Warning System (TAWS) and Enhanced Ground Proximity Warning System (EGPWS) that alerts the pilot of imminent dangers.

Flight Controls

The flight control system (FCS) architecture and pilot controls of the *Helix* were carefully designed to match the varying flight conditions pertaining to helicopter and airplane modes. A fly-by-wire architecture with quadruple redundancy is used to carry control signals along different paths throughout the fuselage for increased safety.

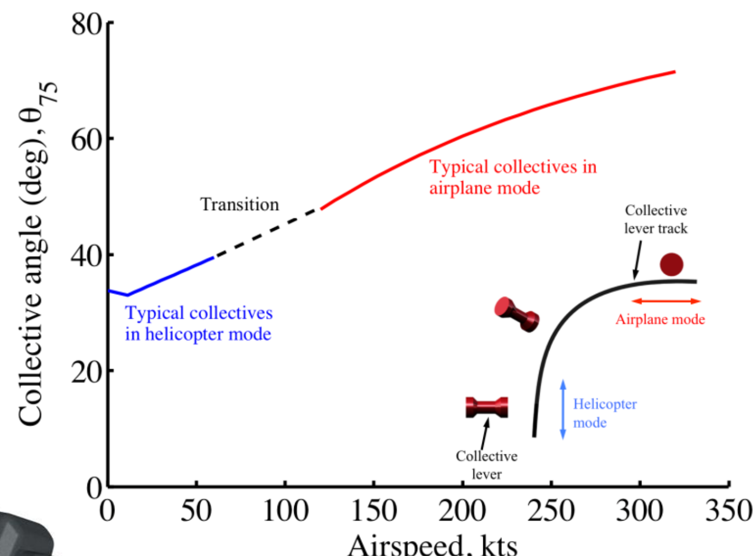


Controls

- ✓ A **right-handed joystick** provides cyclic control in helicopter mode and pitch/roll inputs in airplane mode
- ✓ A novel **lever and track mechanism** provides up-down collective motion in helicopter mode, and fore-aft throttle motion in airplane mode
  - o The mechanism can be used with ease by both helicopter and airplane pilots, thereby minimizing the possibility of control reversal mishaps
- ✓ Conventional **foot pedals** are used for yaw control in both helicopter and airplane modes

Automatic Flight Control System (AFCS)

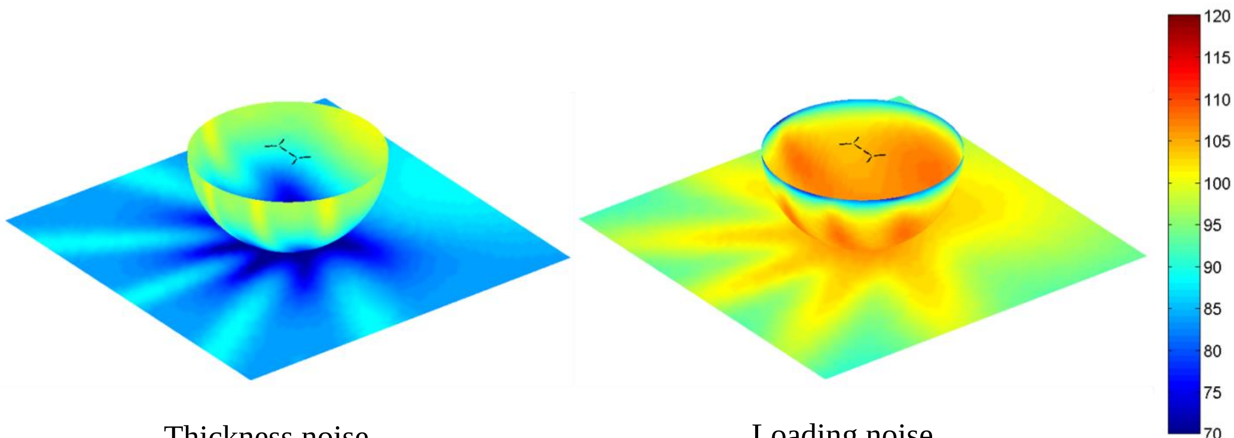
- ✓ The AFCS is designed to ensure smooth transition from helicopter to airplane mode and vice-versa through extensive and **continuous control mixing**
- ✓ In case of a failure of a critical system (i.e. OWE/VDR system), the AFCS automatically executes a pre-programmed failure logic sequence



Acoustics

The *HeliX* complies with the latest FAA noise certification standards for a civilian tiltrotor aircraft. These standards were updated to concur with ICAO regulations. The regulations define overflight reference measurement points where the total vehicle noise must not exceed 100.8 EPNdB.

- ✓ The *HeliX* **noise signatures were well below the prescribed limits** in both helicopter and airplane modes.
- ✓ Determination of A-weighted sound levels indicated low levels of annoyance to the human-ear
- ✓ Thickness, loading, and total sound levels are at least 10% lower than FAA regulations at the critical overflight reference points



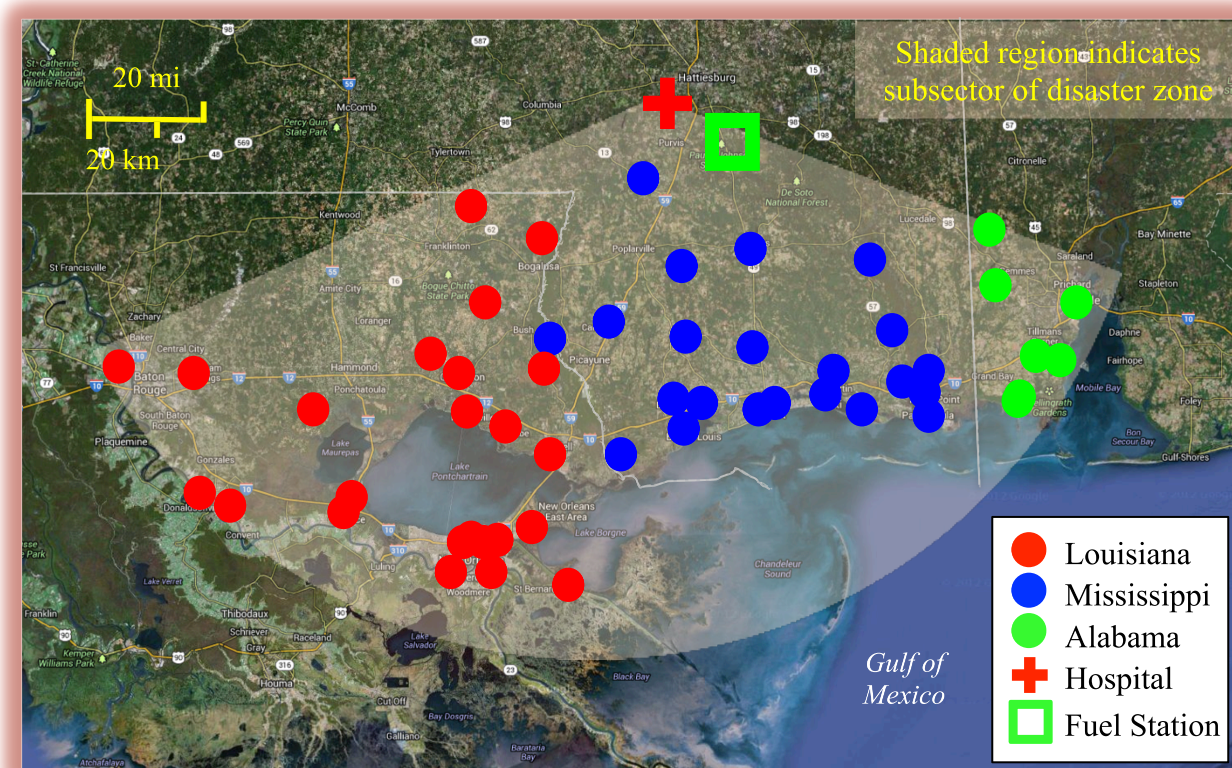
Thickness noise   Loading noise

Search and Rescue (SAR) Simulation

To showcase the performance of the *HeliX*, a search and rescue simulation was designed, modeling the Hurricane Katrina disaster of 2005. A fleet of two identical aircraft were routed to rescue destinations, until approximately 200 casualties had been hoisted on onboard and delivered to a medical facility. The simulation was run for fleets of three different helicopter platforms: the *Dolphin*, *Jayhawk*, and the *HeliX*.

OPTIMUM ROUTE PLANNING:
Routes for each fleet aircraft are planned to first maximize the chance of casualty survival and then to minimize distance travelled, thus minimizing fuel costs. Scouting aircraft or ATC can use aircraft location and status information, obtained periodically and without pilot involvement via a datalink, to compile a database of rescue destinations. Confirmed routes can then be relayed back to the navigation system of each aircraft.

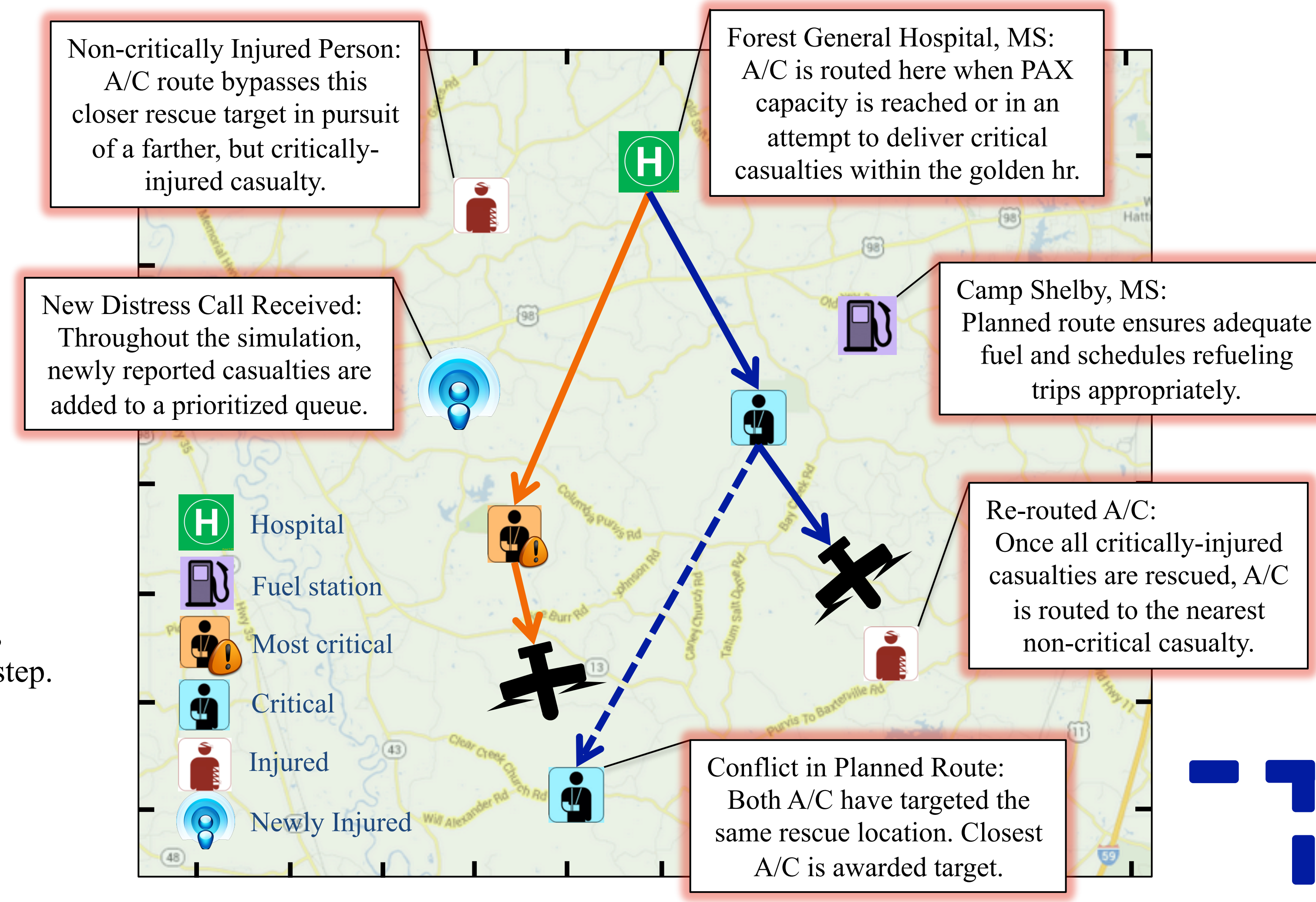
SEARCH & RESCUE SIMULATION: HURRICANE KATRINA



Above: *Dots of Distress…* For this exercise, the Gulf Coast populated with rescue destinations selected from Hurricane Katrina flood and damage statistics to simulate a realistic disaster scenario. This database supplied dynamic intelligence for the simulation, with new targets being introduced into the fleet's queue of destinations at each new time step.

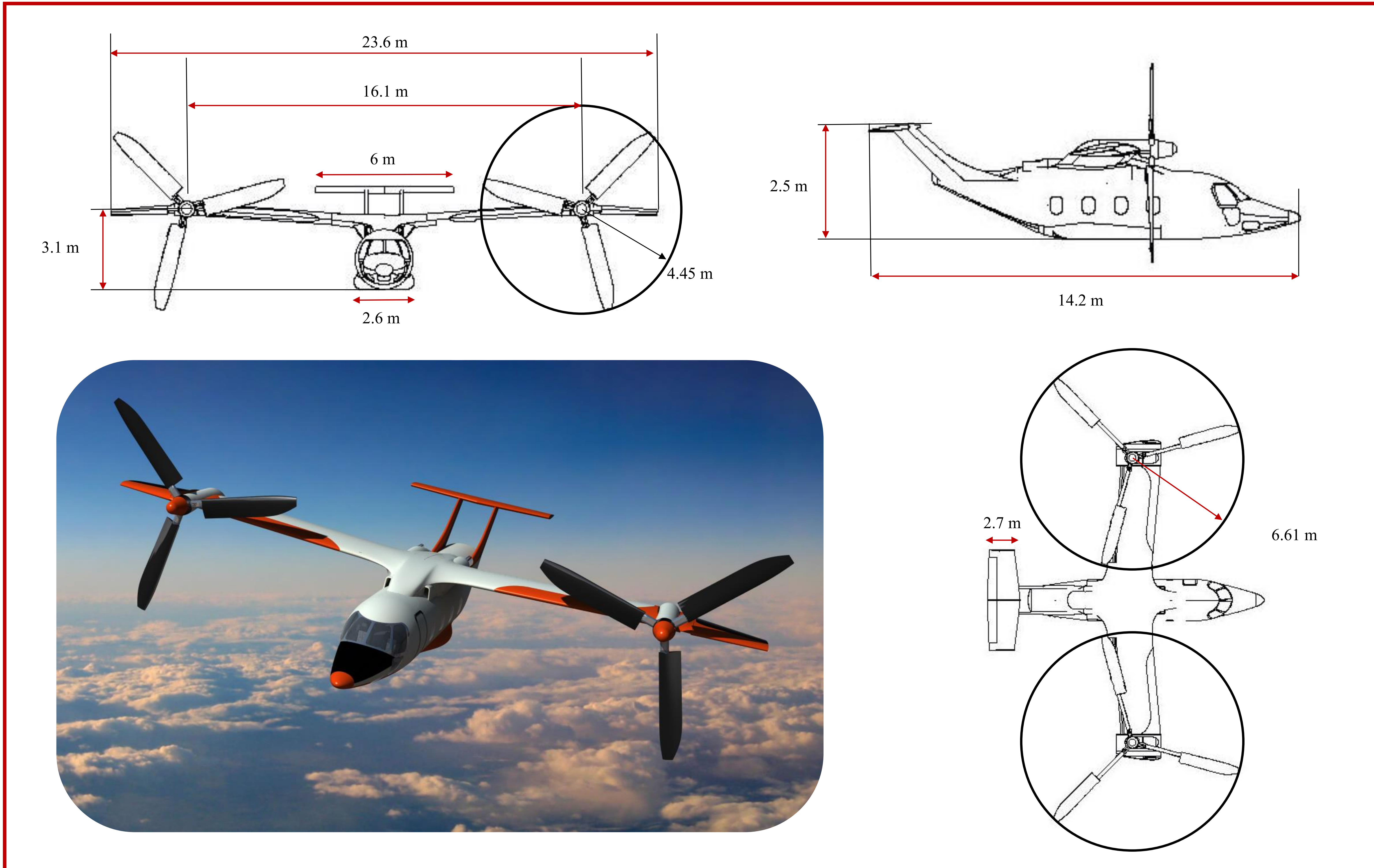
		Dolphin	Jayhawk	HeliX	
Simulation Results	PAX Capacity	3	4	6	12
	Rescue Rate [PAX/hr]	2.22	2.44	4.18	6.67
	Total Time [hr]	38.5	42	25	16.5
	Total Fuel [kL]	51.1	45.0	48.8	26.5
	Golden Hour Ratio (critical casualties)	0.33	0.37	0.71	0.79
	Golden Hour Ratio (critical & non-critical casualties)	0.55	0.57	0.74	0.86
	Relative Productivity [PAX/hr/L]	1.00	1.17	1.86	5.45
Scaled Results	**Potential Impact for a Full-Scale Disaster of Katrina-Magnitude (scale 1:175)**				
	Total Fuel [kL]	9,085	7,571	8,517	4,542
	Relative Fuel Consumption	1.00	0.83	0.93	0.50
	Fuel Cost [2013 US$]	$ 8.4 million	$ 7.0 million	$ 7.8 million	$ 4.2 million

Below: *Connecting the Dots…* During the simulation, a small fleet of two aircraft were routed to known distress locations via an optimized path, which first prioritized the most critical casualties and secondly minimized the distance traveled and thus fuel burned.



Left: *Resulting Rescue Report…*
The performance of three vehicle platforms was evaluated throughout the SAR simulation. The *HeliX* was the clear winner, rescuing the allotted 200 casualties in approximately 40% of the total time and for just over half the fuel as compared to the Dolphin and Jayhawk of the U.S. Coast Guard, who were recognized as the best performing entity during Katrina relief efforts. Scaling these results to a disaster of similar magnitude, the *HeliX* could have offered potential rescue expense savings on the order of millions of dollars.

On the path to rescue!


23.6 m
16.1 m
6 m
3.1 m
4.45 m
2.6 m
2.5 m
14.2 m
2.7 m
6.61 m